AN IMPROVED NEGATIVE SELECTION ALGORITHM BASED ON THE HYBRIDIZATION OF CUCKOO SEARCH AND DIFFERENTIAL EVOLUTION FOR ANOMALY DETECTION

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In the name of ALLAH,

The Most Compassionate, The Most Merciful

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ABSTRACT

The biological immune system (BIS) is characterized by networks of cells, tissues, and organs communicating and working in synchronization. It also has the ability to learn, recognize, and remember, thus providing the solid foundation for the development of Artificial Immune System (AIS). Since the emergence of AIS, it has proved itself as an area of computational intelligence. Real-Valued Negative Selection Algorithm with Variable-Sized Detectors (V-Detectors) is an offspring of AIS and demonstrated its potentials in the field of anomaly detection. The V-Detectors algorithm depends greatly on the random detectors generated in monitoring the status of a system. These randomly generated detectors suffer from not been able to adequately cover the non-self space, which diminishes the detection performance of the V-Detectors algorithm. This research therefore proposed CSDE-V-Detectors which entail the use of the hybridization of Cuckoo Search (CS) and Differential Evolution (DE) in optimizing the random detectors of the V-Detectors. The DE is integrated with CS at the population initialization by distributing the population linearly. This linear distribution gives the population a unique, stable, and progressive distribution process. Thus, each individual detector is characteristically different from the other detectors. CSDE capabilities of global search, and use of Lévy flight facilitates the effectiveness of the detector set in the search space. In comparison with V-Detectors, cuckoo search, differential evolution, support vector machine, artificial neural network, naïve bayes, and k-NN, experimental results demonstrates that CSDE-V-Detectors outperforms other algorithms with an average detection rate of 95.30% on all the datasets. This signifies that CSDE-V-Detectors can efficiently attain highest detection rates and lowest false alarm rates for anomaly detection. Thus, the optimization of the randomly detectors of V-Detectors algorithm with CSDE is proficient and suitable for anomaly detection tasks.

ABSTRAK

Sistem imun biologi (BIS) mempunyai ciri-ciri rangkaian sel-sel, tisu, dan organ berkomunikasi dan bekerja secara selaras. Ia juga mempunyai keupayaan untuk belajar, mengiktiraf, dan ingat, sekali gus menyediakan asas yang kukuh untuk pembangunan Sistem imun kecerdasan buatan (AIS). Sejak kemunculan AIS, terbukti kebolehgunaannya di dalam bidang kecerdasan komputer. Real-Valued Negative Selection Algorithm with Variable-Sized Detectors (V-Detectors) adalah tergolong didalam bidang AIS dan telah menunjukkan potensinya di dalam bidang pengesanan anomali. Algoritma V-Detectors menjana pelbagai pengesan secara rawak dalam memantau status sistem. Pengesan yang telah dijana secara rawak ini tidak dapat meliputi secukupnya ruang non-self yang mengurangkan prestasi pengesanan algoritma V-Pengesan. Oleh itu, kajian ini telah mencadangkan CSDE-V-Detectors yang melibatkan penggunaan penghibridan Cuckoo Search (CS) dan Differential Evolution (DE) dalam mengoptimumkan pengesanan rawak bagi V-Pengesan. DE telah disepadukan dengan CS pada populasi pengawalan dengan mengagihkan populasi secara linear. Pengedaran linear ini memberikan satu proses pengedaran unik, stabil dan progresif kepada populasi tersebut. Oleh itu, setiap pengesan adalah bersifat berbeza daripada pengesan yang lain. Keupayaan CSDE dalam carian global dan penggunaan Lévy flight memudahkan keberkesanan set pengesan dalam ruang carian. Di dalam perbandingan dengan V-Pengesan, cuckoo search, differential evolution, mesin vector sokongan, rangkaian neural buatan, bayes naïf, dan k-NN, keputusan eksperimen pada set data tertentu yang dipilih daripada pangkalan data yang berbeza menunjukkan bahawa CSDE-V-Detectors melebihi performa algoritma lain secara purata dengan kadar 95.30%. Ini menunjukkan CSDE-V-Detectors lebih efisyen sehingga boleh mencapai kadar pengesanan yang tinggi dan kadar penggera palsu yang paling rendah pada pengesenan anomali. Oleh itu, pengoptimuman secara pengesana rawak bagi algoritma V-Pengesan dengan CSDE adalah cekap dan sesuai bagi melaksanakan tugas-tugas pengesanan anomali.

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LIST OF ALGORITHMS

LIST OF SYMBOLS AND ABBREVIATIONS

$\subset$	–	Proper subset
$\subseteq$	–	Subset
$\in$	–	Element of
U	–	Universe
$\mathbb{R}$	–	Real number set
$\cap$	–	Intersection
$\emptyset$	–	Empty set
Nc	–	Total number of clones
N	–	Size of the antibody pool
ab	–	Antibody
ag	–	Antigen
L	–	Length of bit string
r_s	–	Self radius
r_d	–	Detector radius
T_{max}	–	Maximum number of detector
m_{max}	–	The counter limit
c_0	–	Estimated coverage
$D(X_i, c_d)$	–	Euclidean distance between self sample X_i and detector d based on detector centre c_d
X	–	Set of self samples
$\forall$	–	For all or for any
$\exists$	–	There exists
p_a	–	Probability of host discovering a cuckoo's egg
Γ	–	Gamma distribution
CO_2	–	Carbon dioxide
$MaxGen$	–	Maximum number of generation
D	–	Set of detectors
AIS	–	Artificial Immune System
BIS	–	Biological Immune System
NSA	–	Negative Selection Algorithm
V-Detectors	–	Real-Valued Negative Selection Algorithm with Variable-Sized Detectors
CS	–	Cuckoo Search
DE	–	Differential Evolution
CLONALG	–	CLONal selection ALGorithm
AINE	–	Artificial Immune NEtworks
DCA	–	Dendritic Cell Algorithm

RNSA	–	Real-Valued Negative Selection Algorithm with Constant-Sized Detectors
TP	–	True Positive
FN	–	False Negative
FP	–	False Positive
TN	–	True Negative
DR	–	Detection Rate
FAR	–	False Alarm Rate
SP	–	Specificity
PPV	–	Positive Predictive Value
MCC	–	Matthews Correlation Coefficient
SVM	–	Support Vector Machine
ANN	–	Artificial Neural Network
k-NN	–	k-Nearest Neighbor
NB	–	Naïve Bayes
MATLAB	–	MATrix LABoratory
APC	–	Antigen Presenting Cell
MHC	–	Major Histocompatibility Complex
NAT	–	Network Affinity Threshold
ARB	–	Artificial Recognition Ball
SNS	–	Self-Non_Self
PSO	–	Particle Swarm Optimization
GA	–	Genetic Algorithm
exp	–	exponential
bin	–	binomial
OSH	–	Optimal Separating Hyperplane
QP	–	Quadratic Programming
EIA	–	Energy Information Administration
OPEC	–	Organization of the Petroleum Exporting Countries
PC	–	Personal Computer
CPU	–	Central Processing Unit
RAM	–	Random Access Memory
ROC	–	Receiver Operating Characteristic
AUC	–	Area Under the ROC Curve

LIST OF PUBLICATIONS

Journals:

(i) Ayodele Lasisi, Rozaida Ghazali, Mustafa Mat Deris, Tutut Herawan, and Fola Lasisi, "Extracting Information in Agricultural Data Using Fuzzy-Rough Sets Hybridization and Clonal Selection Theory Inspired Algorithms," *International Journal of Pattern Recognition and Artificial Intelligence*, Vol. 30, No. 09, pp. 1660008, 2016.

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CHAPTER 1

INTRODUCTION

1.1 Background of the Research

The birth of Artificial Immune System (AIS) has brought a new lease of life in discovering changes in data and system as a whole. The inspiration from Biological Immune System (BIS), which is a unique, robust and orchestrated system against the influx of pathogens, viruses, and bacteria, makes AIS a force to be reckoned with. It could prove a vital point in overcoming the various security and detection problems in existence because the exact purpose of the Immune system still remains hidden to researchers and computer scientists. Varieties of detection techniques have evolved over the years and they have produced amazing results for both known and unknown discoveries. As improvements are made for efficiency, the $not - yet - seen$ lethal elements always have a way of bypassing the defense systems of the algorithms due to inbuilt obfuscation methods. Anomaly detection, a one-class classification problem, where a single class of object is described and distinguished from all other types of objects [1], encompasses the overall functions of the AIS. Task of anomaly detection is to classify an element as $normal$ or $abnormal$ within a given feature space [2], and their targeted aim is to detect abnormal behaviours of system that contradicts to the normal functioning of the system [3, 4]. Negative Selection Algorithm (NSA) [5], which is well rooted in distinguishing between self and non-self, is an AIS model for tackling anomaly detection problems in an attempt to speed up detection accuracy of novel attack patterns.

The real-valued negative selection algorithm with variable-sized detectors (V-Detectors) [6] is employed for use in this research. It models the biological functionalities of the T-cells in protecting the body by censoring and eliminating alien invaders called pathogens. The development process emanates from the thymus and differentiates into matured T-cells without mapping and reacting to self antigens. They are now granted passage into the body circulatory system to fulfil its purpose for existence, which is detecting non-self antigens and adequately causing their annihilation. At the core of the algorithm is the matching rule that matches the antibodies to the antigens, and also the self radius which is a determinant in producing detectors. The efficiency of the V-Detectors is affected by the random process of generating detectors. As such, more productive ways of producing robust and competent detectors are devised by researchers. One of such channels lies with metaheuristic algorithms which are natural optimization techniques. Through mutation, crossover, and selection, global optimality can be achieved. Therefore, a hybridized optimization algorithm based on Cuckoo Search (CS) [7] and Differential Evolution (DE) [8] is proposed as an alternative detector generator for the V-Detectors. This infusion of both metaheuristic algorithms makes use of Lévy flight for its search ability, thereby enabling global search convergence [9].

Increased performance of the V-Detectors can thus be obtained with the hybridized optimization algorithm of CS and DE. The proposed anomaly detection method can assist in effectively checking a system in order to maintain its normal functionality and triggering suspicion of any abnormality that could arise.

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